

Highlights from the ANTARES neutrino telescope

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the ANTARES Collaboration

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CENTRE DE PHYSIQUE DES
PARTICULES DE MARSEILLE

CPPM

Outline

The ANTARES Neutrino Telescope

Detection Principle

Diffuse Flux

Diffuse Flux searches with reduced search window

Point Source search

Multi Messenger Program

Dark Matter

Summary & Outlook



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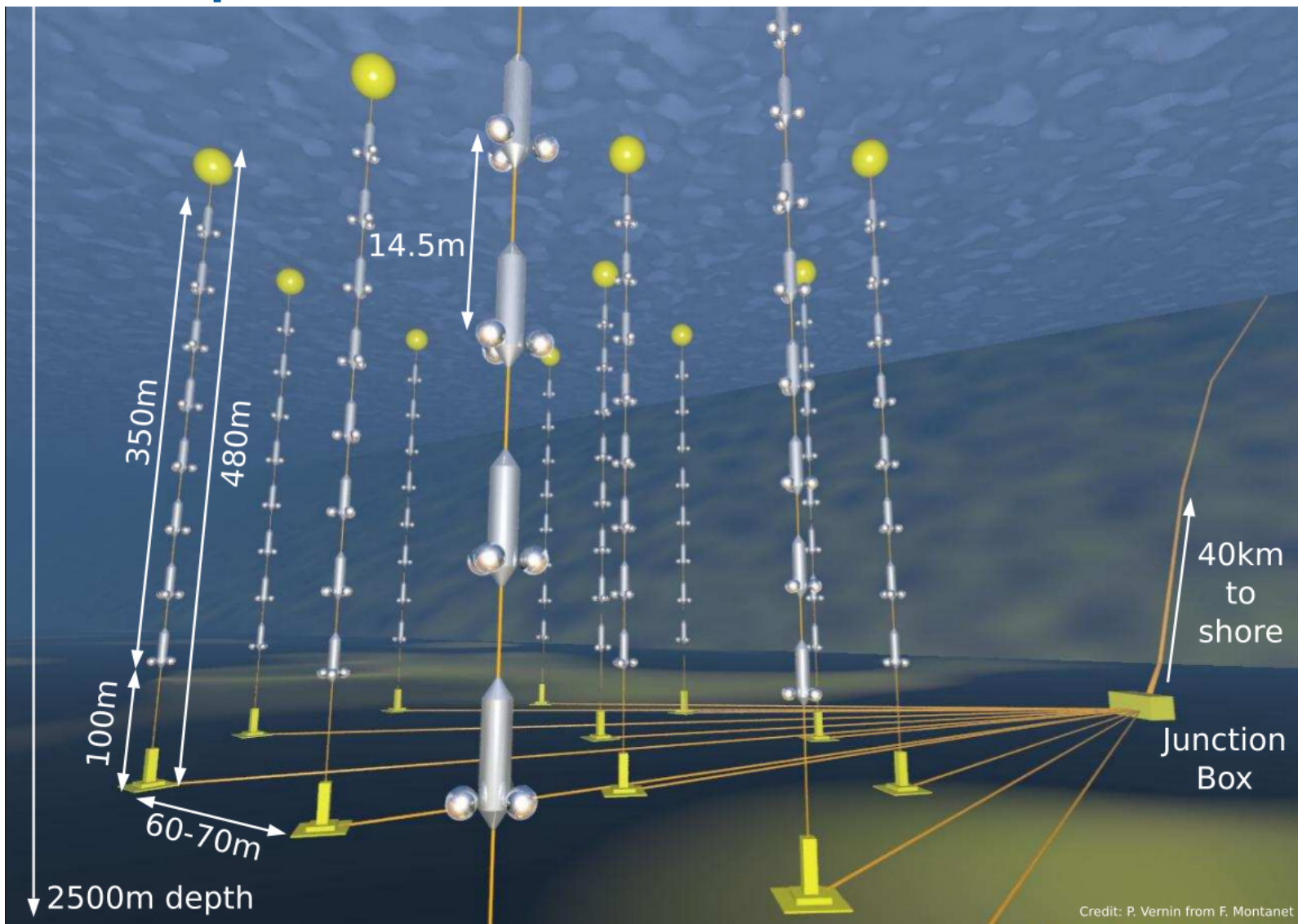
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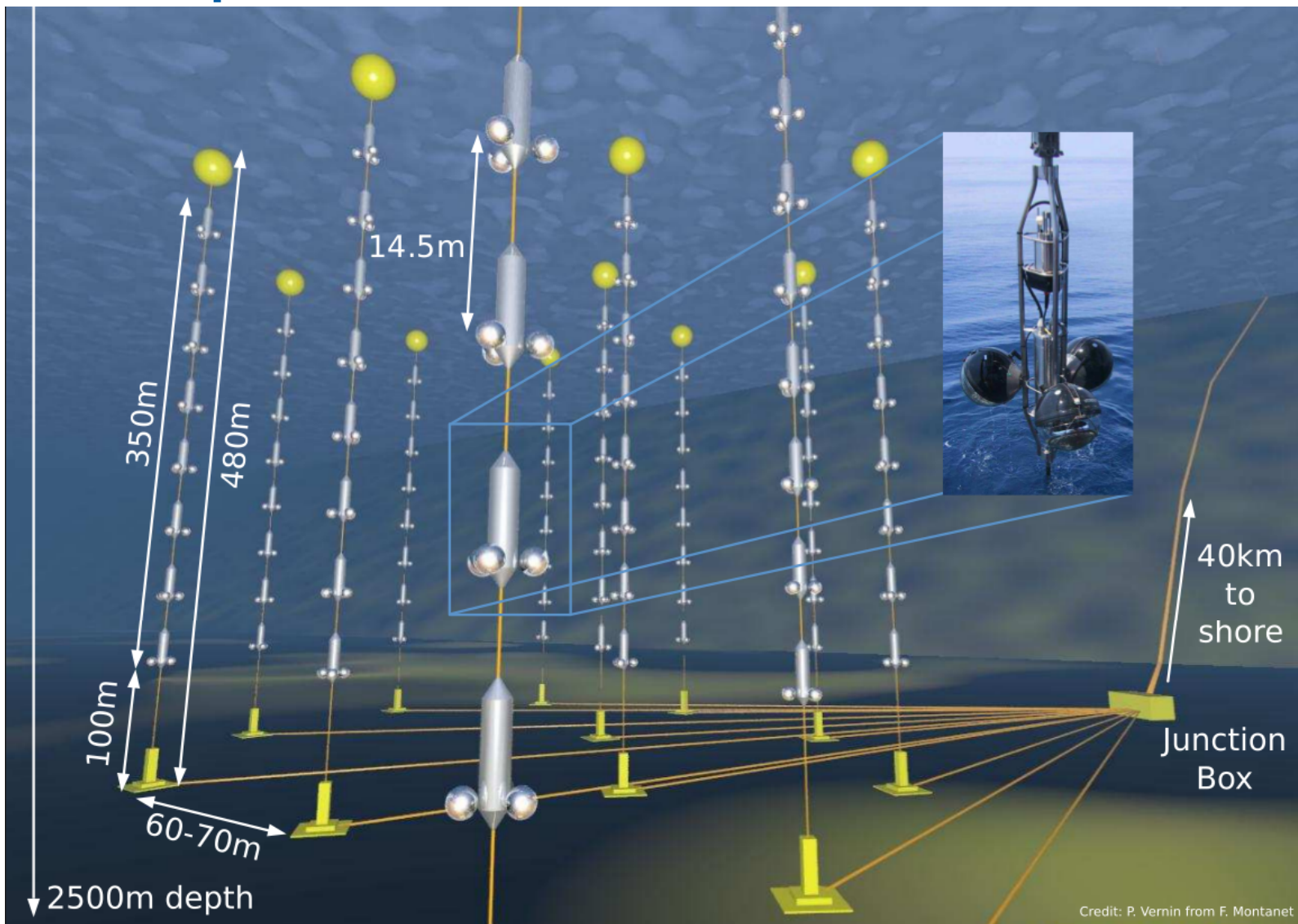
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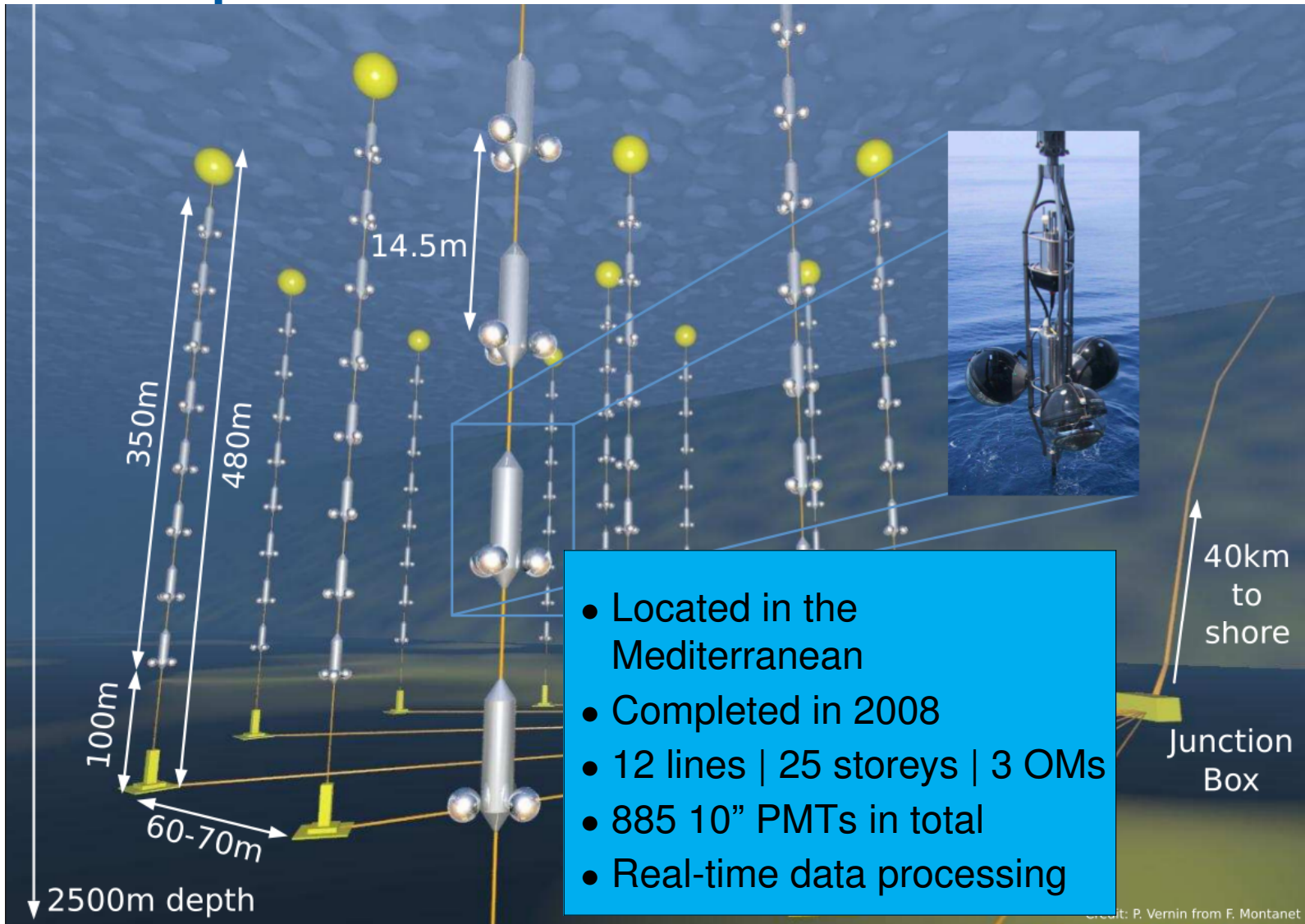
Setup



Setup



Setup



Scientific Program

- Neutrino astrophysics
 - Diffuse fluxes
 - Point sources
- Multi-messenger studies
 - Prompt alerts: TAToO, GW150914 follow up ...
 - Transient gamma & X-ray sources
 - GRBs
- Dark Matter searches
- Study of atmospheric neutrinos, oscillations, atmospheric muons, cosmic-ray anisotropy ...
- Particle searches: nuclearites, monopoles ...
- Acoustic neutrino detection
- Earth and Sea sciences
- ...

Partially covered here

Not covered here



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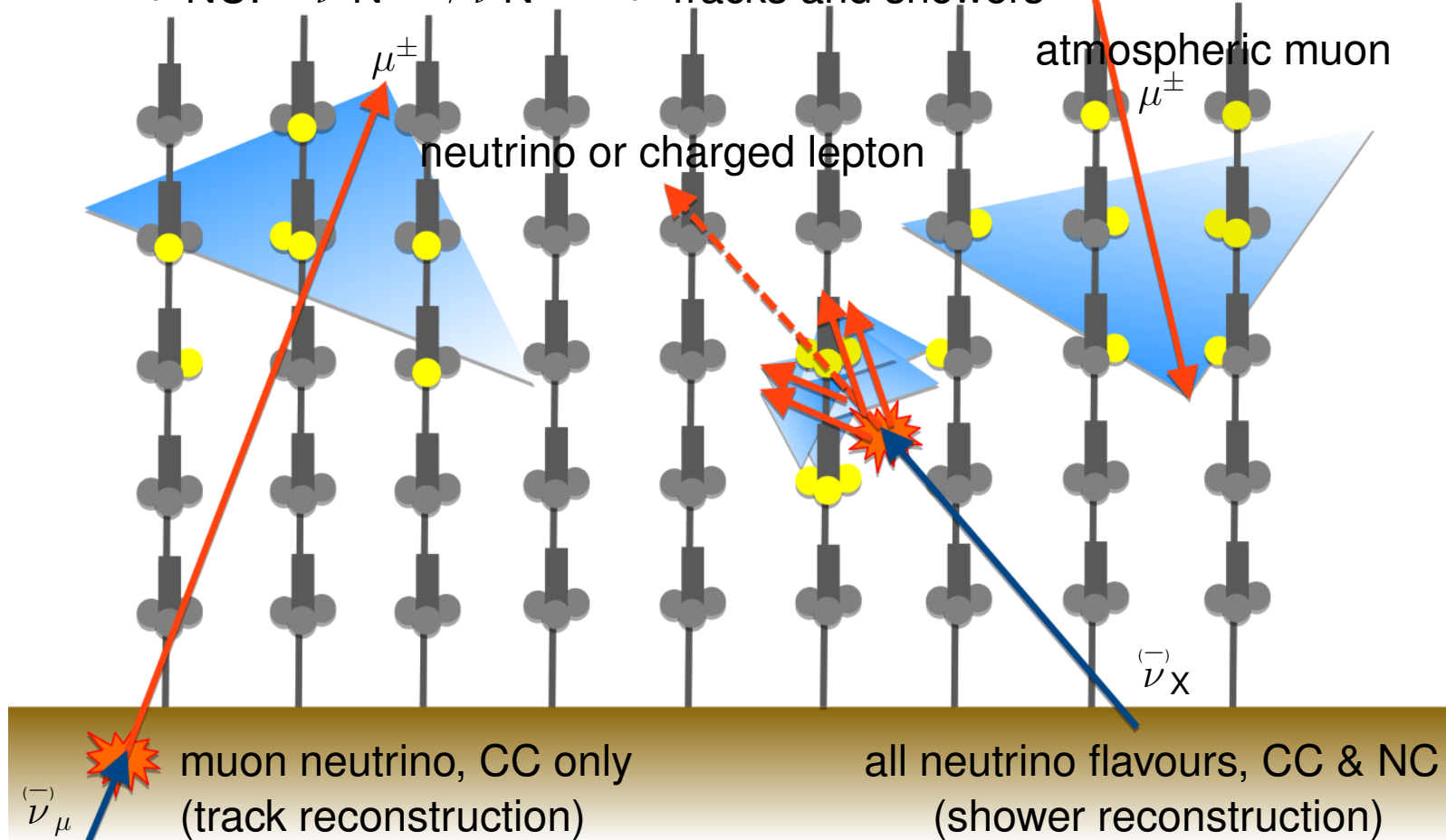
Detection Principle

Neutrino interactions:

- CC: $\nu_l N \xrightarrow{W} l X$
- NC: $\nu N \xrightarrow{Z} \nu N$

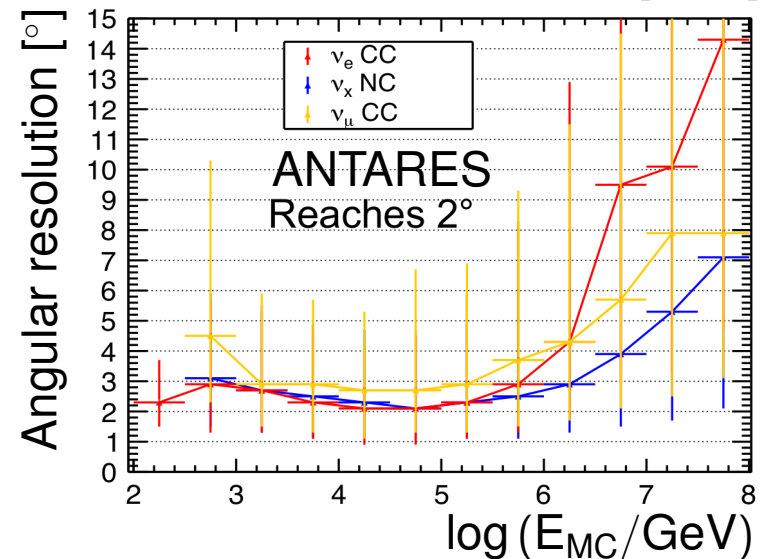
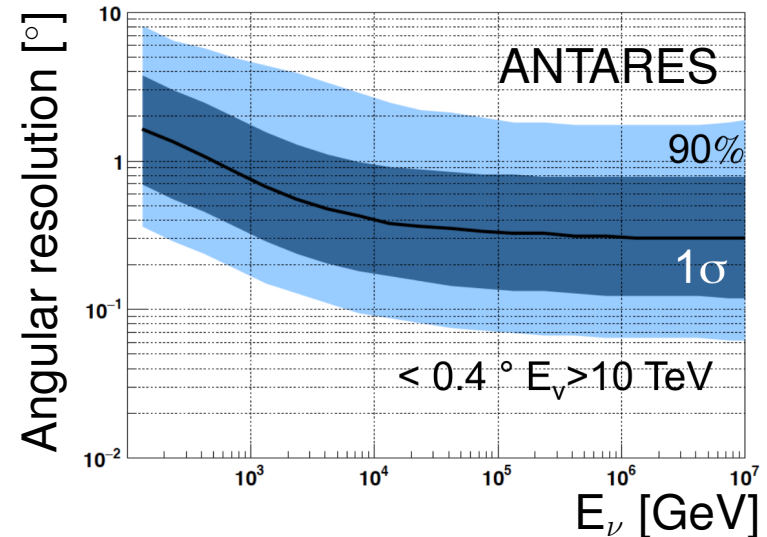
Neutrino topologies:

- Interaction (CC/NC)
- lepton output (e, μ, τ)
- Tracks and showers



Performance

- Tracks best suited for astronomy
- Median $< 0.4^\circ$ above 10 TeV
- 90 % purity
- Cascade events (upgoing) also used for astronomy
- Shower confined within ~ 10 m
- Angular resolution 3°
- Energy resolution better than $\sim 10\%$ in a wide energy range



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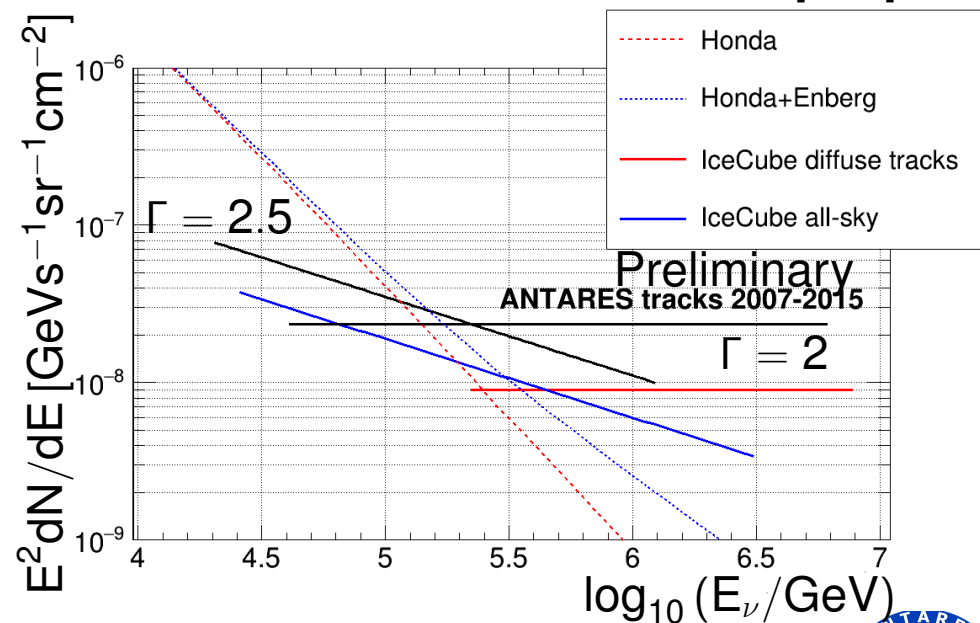
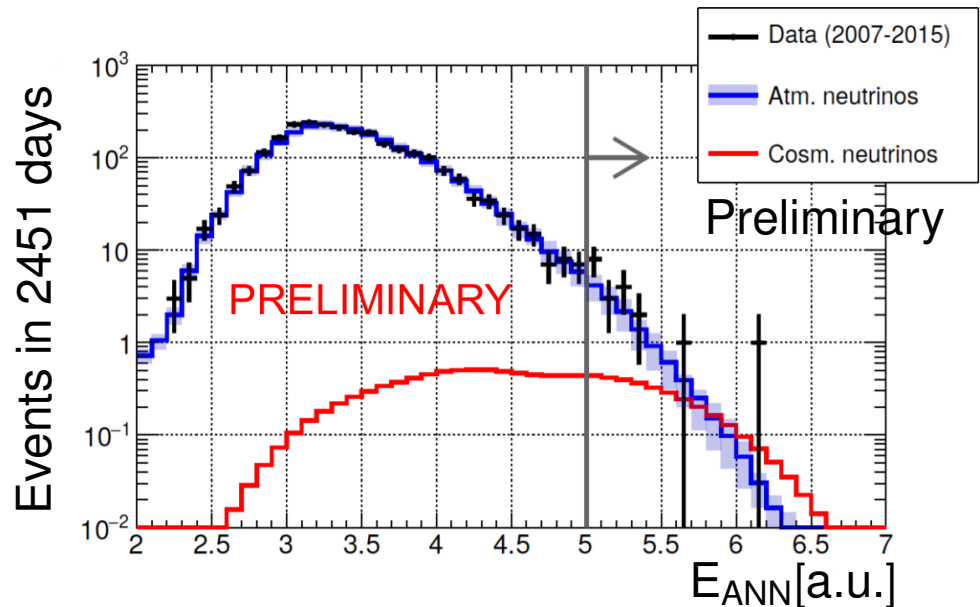
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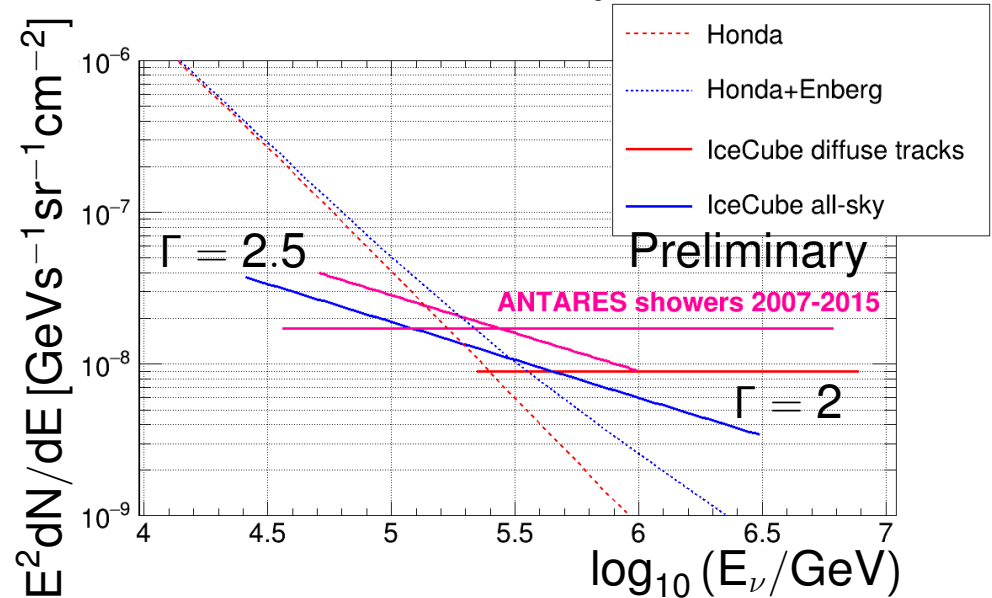
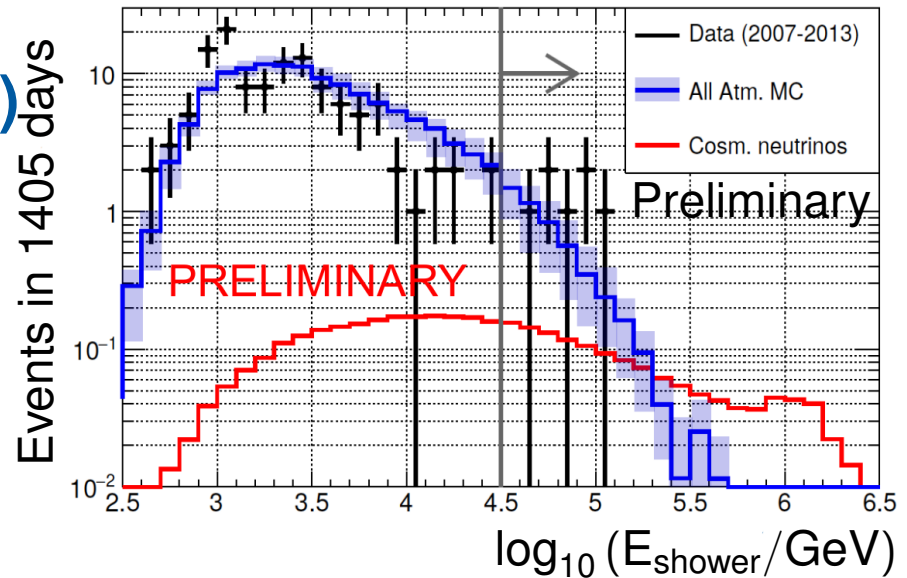
Diffuse Flux (Tracks)

- Data: 2007 - 2015 (2451 livedays)
- Optimization based on IceCube best fit flux (spectral index $\Gamma = 2$ and $\Gamma = 2.5$)
- Variables used checked with test sample
- Above E_{cut} :
 - Observed: 19 evts
 - Background: 13.5 ± 3 evts
 - IceCube-like signal: 3 evts



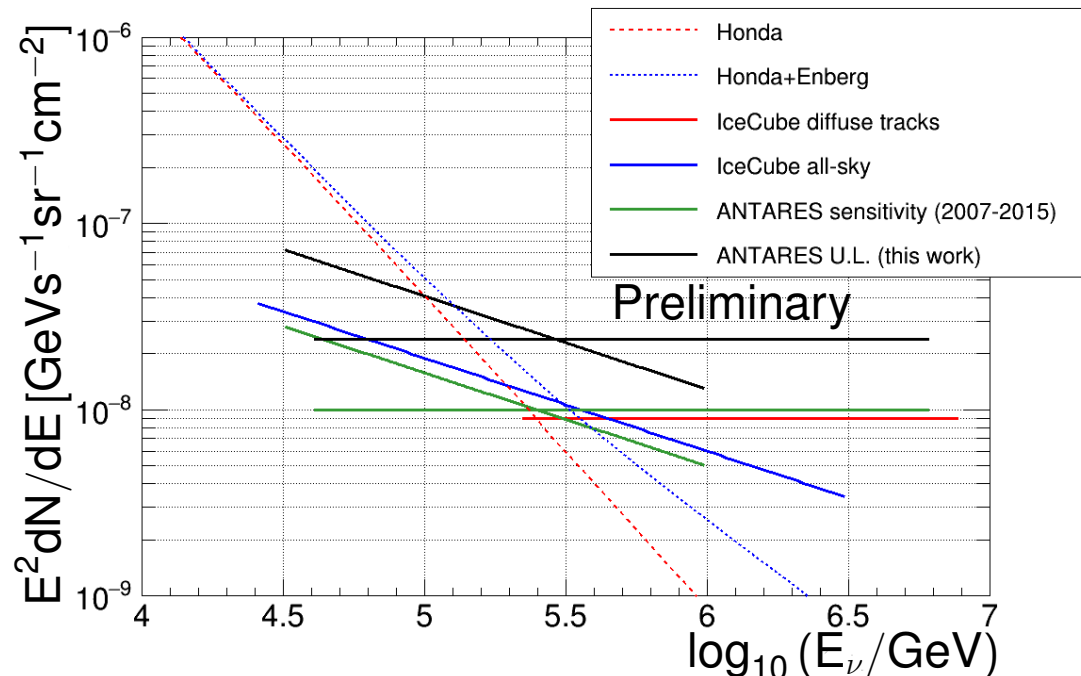
Diffuse Flux (Showers)

- Data: 2007-2013
(1405 livedays)
- Optimization based on IceCube best fit flux (spectral index $\Gamma = 2$ and $\Gamma = 2.5$)
- Variables used checked with test sample
- Above E_{cut} :
 - Observed: 7 evts
 - Background: 5 ± 2 evts
 - IceCube-like signal: 1.5 evts



Diffuse Flux (Combined)

- Combination of the sensitivity from the two independent diffuse flux analyses as: $\frac{1}{S_{\text{Comb}}} = \frac{1}{S_{\text{Showers}}} + \frac{1}{S_{\text{Tracks}}}$
- Upper limit (FC, 90% C.L.) after unblinding of the shower (1405 d, 2007-2013) and the track (2451 d, 2007-2015) samples, compared to the ANTARES sensitivity for the whole data sample and the measurements from IceCube



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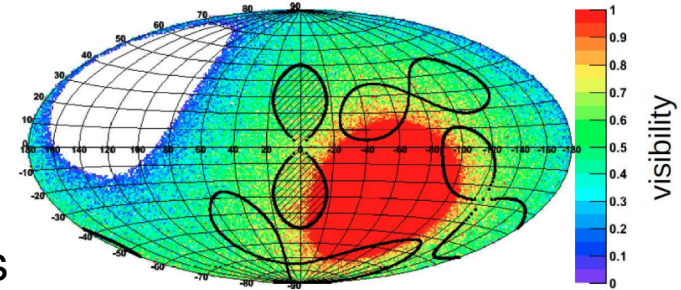
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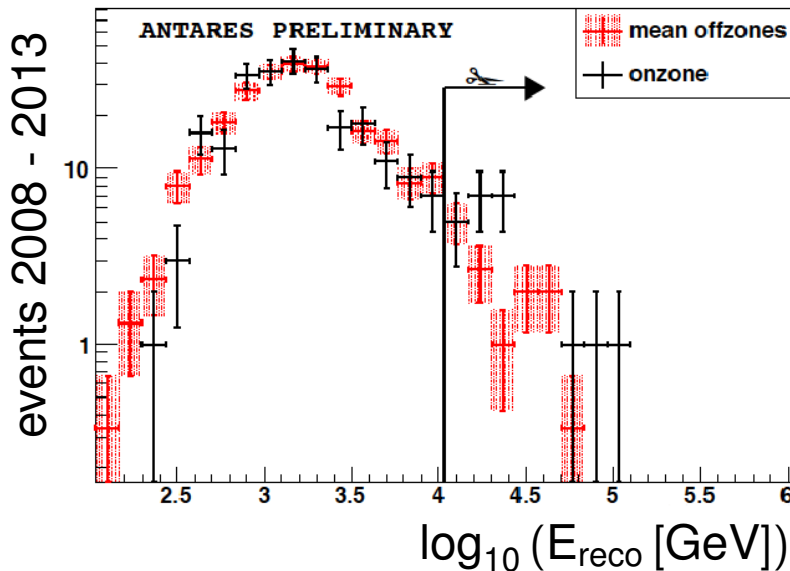


Fermi Bubbles

- Data: 2008 - 2015 (1765 days livetime)
- ν_μ only
- Fermi Bubbles
 - 3 OFF-zone regions of $\Delta\Omega = 0.66$ sr
 - Average expected background : 19.7 evts
 - Observed in the ON-region : 28 evts
 - Previously reported excess reduced to 1.5σ

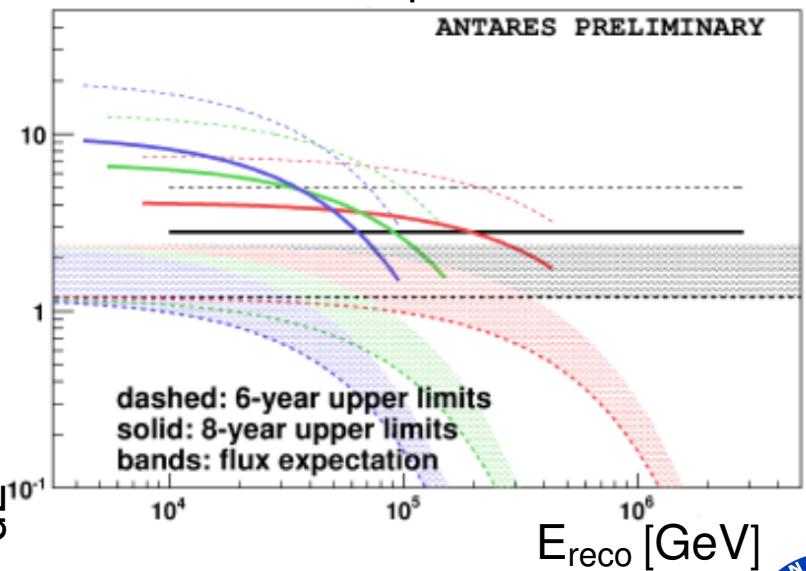


On/Off zones - Gal. coordinates



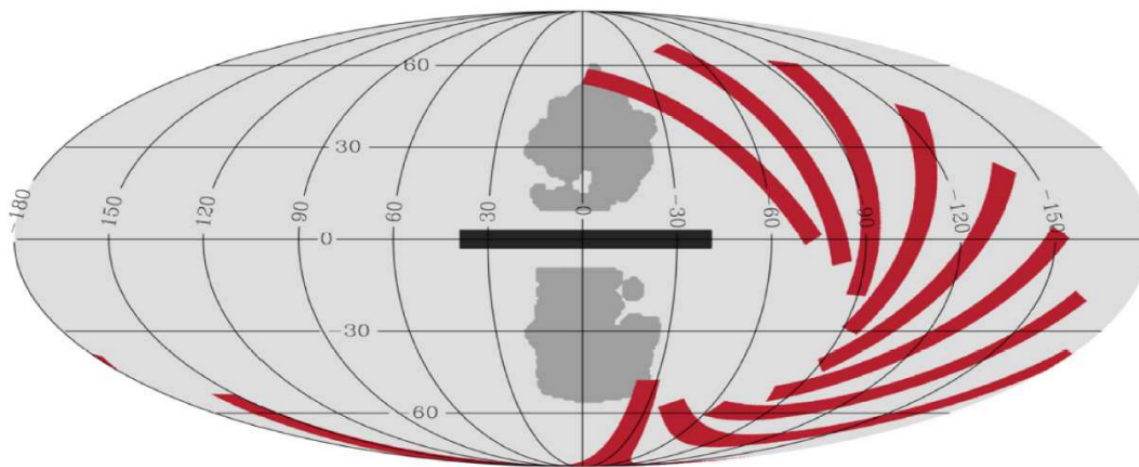
$E^2 \frac{d\phi}{dE} [10^{-7} \text{ GeV s}^{-1} \text{ sr}^{-1} \text{ cm}^{-2}]$

E^{-2} spectrum



Galactic Ridge

- Data: 2007 - 2013 (1622 days)
- ν_μ only
- Cuts optimized for $\Gamma = 2.4 - 2.5$
- Galactic Ridge:
 - 9 OFF-zones
 - Search region $|l| < 30^\circ$, $|b| < 4^\circ$
 - Average expected background : 3.7 evts
 - Observed in the ON-zones : 2 evts
- No excess in the HE neutrinos
- 90 % c.l. upper limits: $3 < E_\nu < 300 \text{ TeV}$



ON/OFF zones
in galactic coordinates



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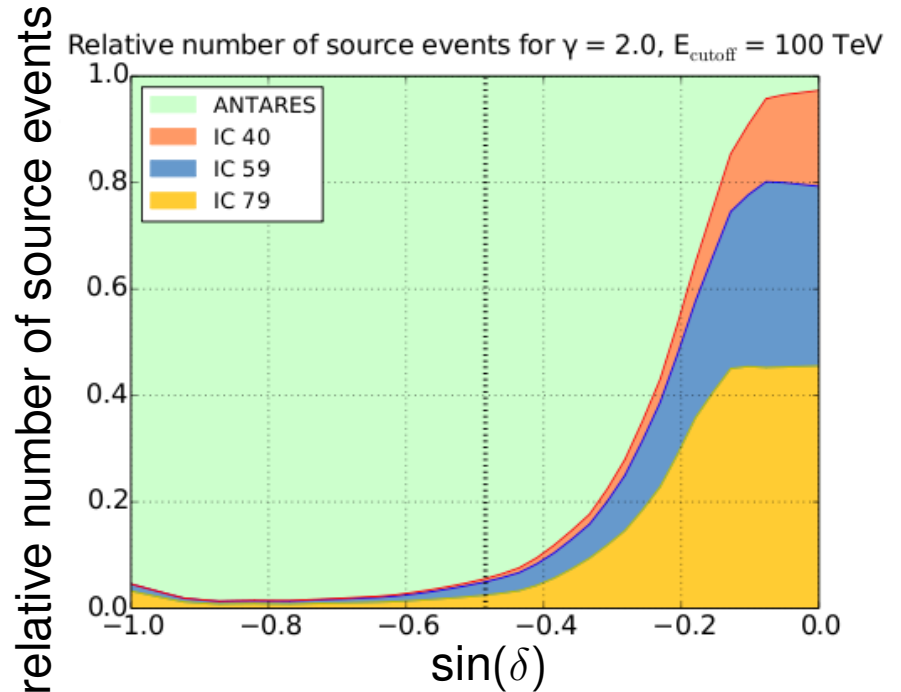
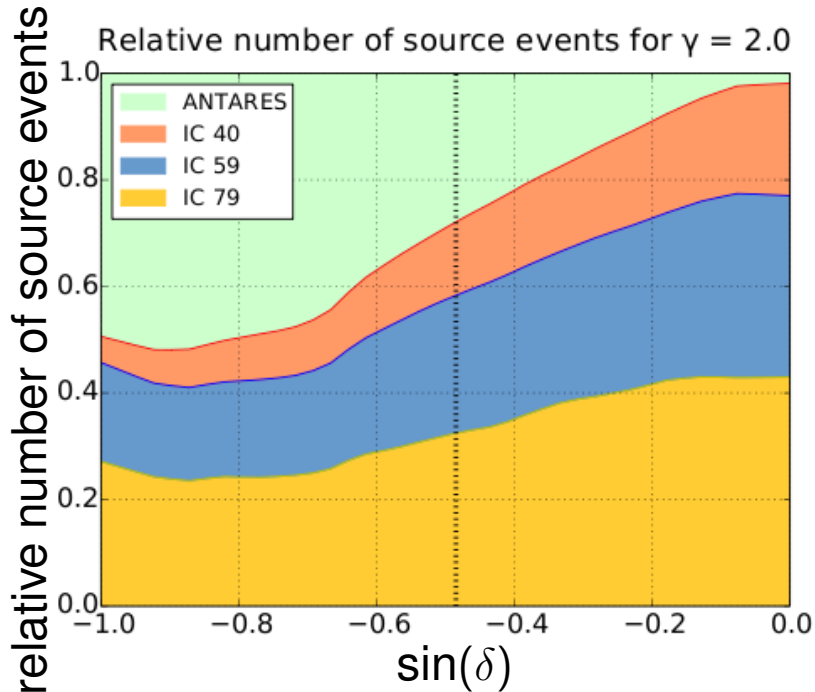
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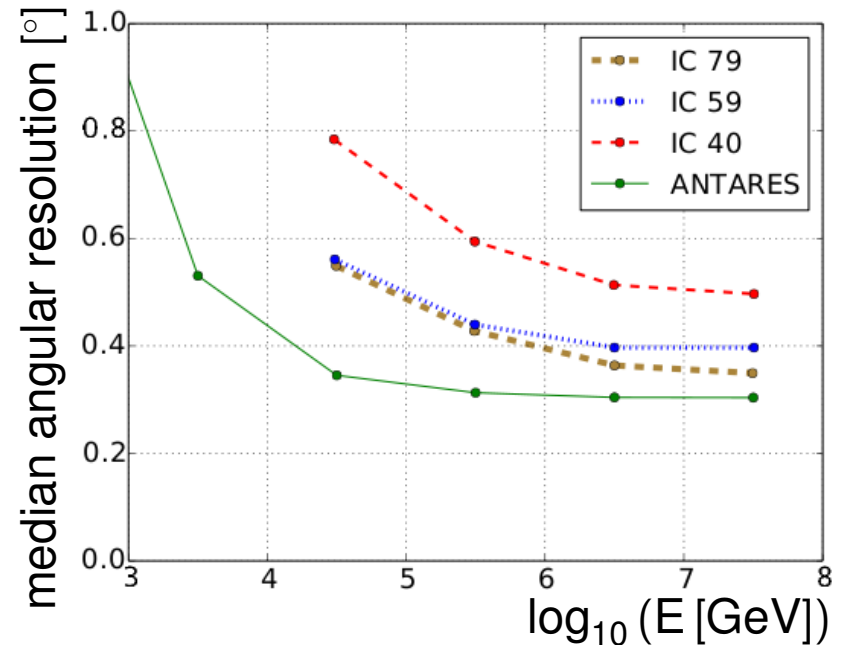
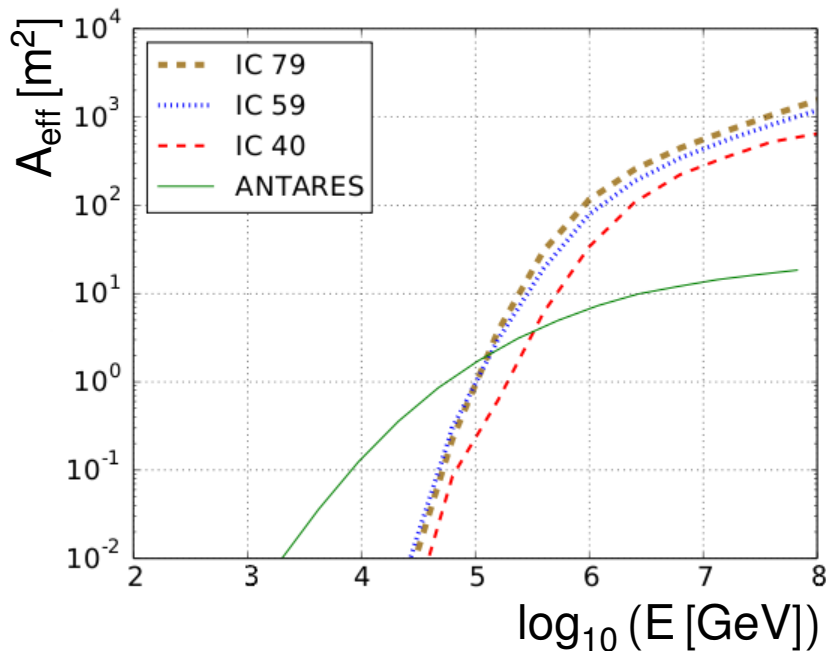
ANTARES-IceCube PS search

- Combined search for neutrino point-sources in the Southern Hemisphere with the ANTARES and IceCube neutrino telescopes, ApJ 823(2016)65
- Southern sky muon tracks



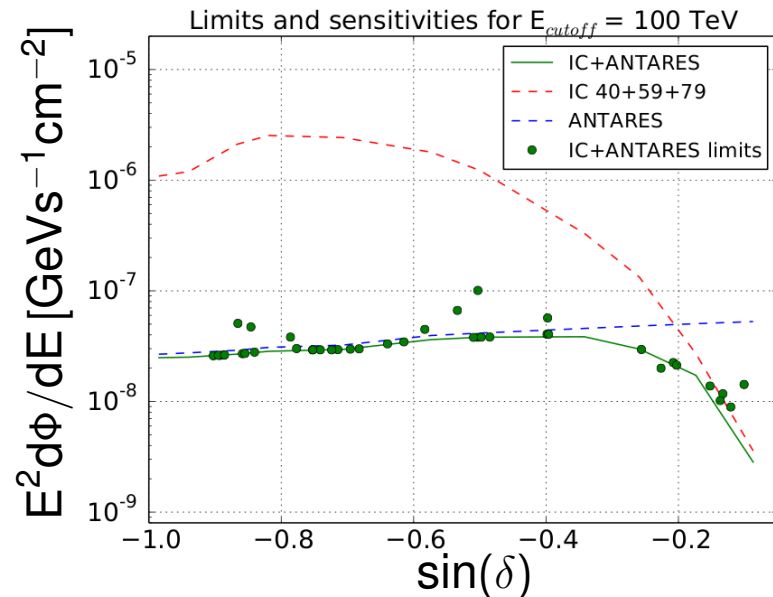
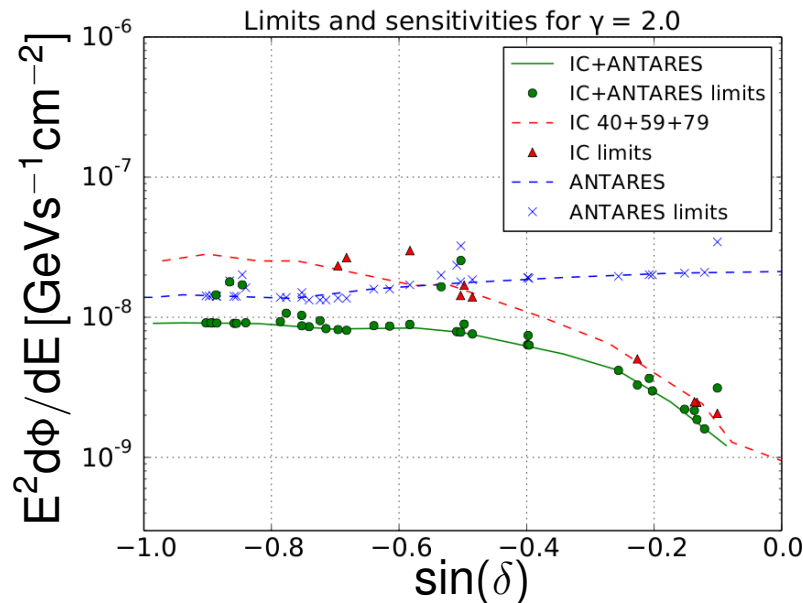
ANTARES-IceCube PS search

- IceCube 2008–2011 + ANTARES 2007–2012 data:
 - IC-40: 375 days of livetime with 22779 events
 - IC-59: 348 days of livetime with 64240 events
 - IC-79: 316 days of livetime with 59009 events
 - ANTARES: 1338 days of livetime with 4136 events



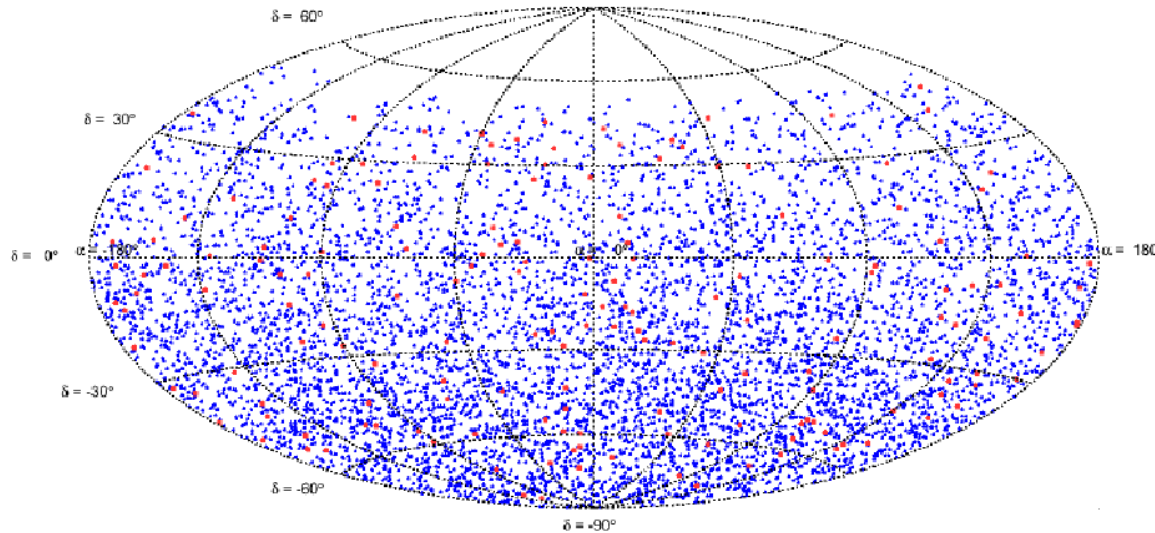
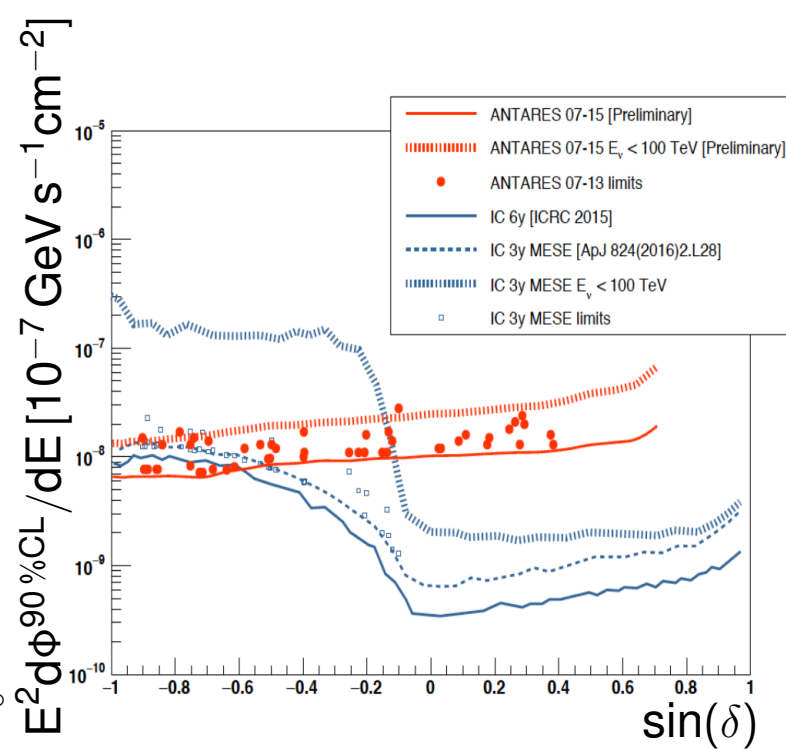
ANTARES-IceCube PS search

- Full sky + 40 sources
(17 extra-galactic + 22 galactic + Galactic Centre)
- Upper limits improvement up to a factor ~ 2
- No significant cluster found, largest excesses:
 - Full sky search:
0.7 σ significance (post-trial) at (RA: 332.8°, δ : 46.1°)
 - Candidate list:
1.2 σ significance (post-trial) for HESS J1741.302



Point Sources

- Data: 2007-2013
(1690 days)
- 6490 tracks, 172 showers
- Unbinned all-sky search
- 54 candidate sources + 8 high energy starting events (HESE) μ
- No significant cluster, largest excess:
 - All-sky: 1.3σ at RA: 311.7° δ : -48.3°
 - Candidate list: 0.75σ for HESS J06302+057



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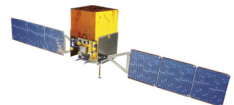
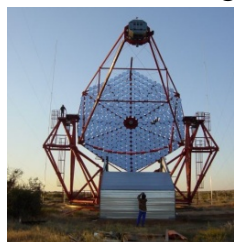
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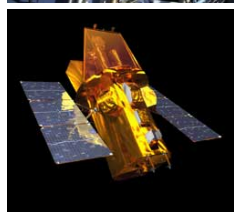
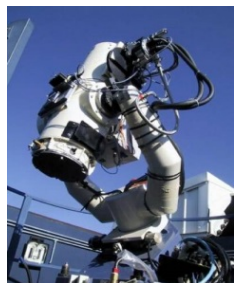
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Increases chances of detection:

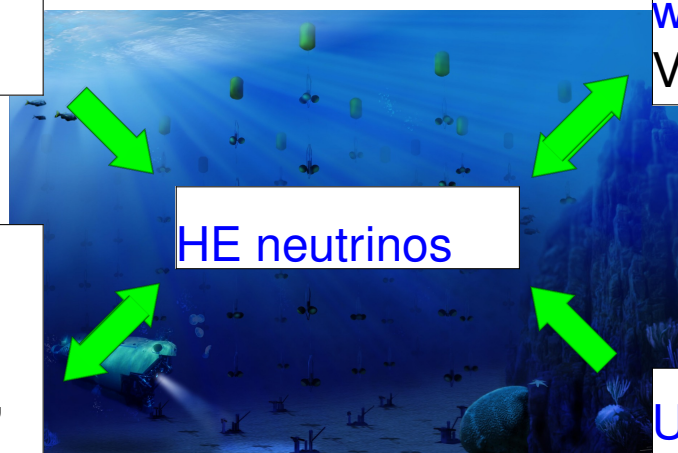
- common sources for different messengers
- limits searches in time and space, low backgrounds
- uncorrelated backgrounds and systematics



GeV-TeV γ -rays
Fermi, HESS,
HAWC



Optic / X-rays
TAROT,
ROTSE, Swift,
ZADKO, MWA,
SUPERB,
MASTER



HE neutrinos

Gravitational
waves
Virgo / Ligo

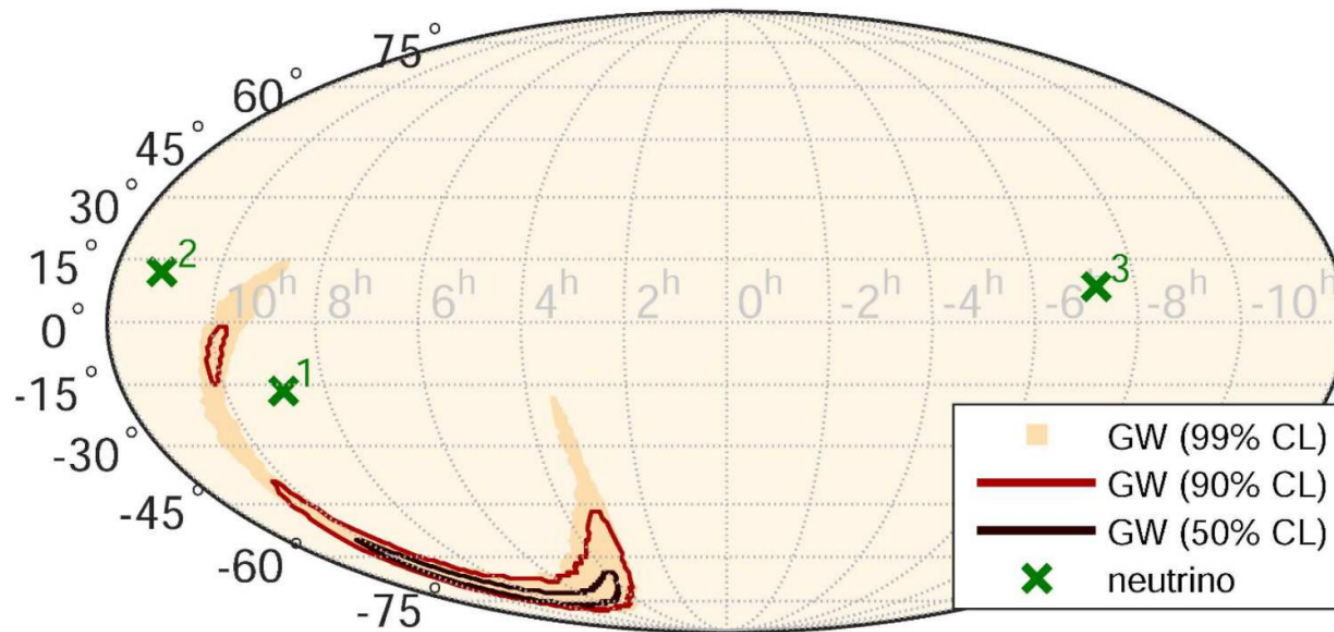


UHECR
Auger, TA



ANTARES GW150914 follow up

- Alert triggered by LIGO on 14/SEP/2015: first Gravitational Wave detected
- Limits from ANTARES dominates below $O(100 \text{ TeV})$
- Size of GW150914 : $590 (\text{°})^2$ ANTARES resolution: $< 0.5 (\text{°})^2$
- Limits on total energy radiated in neutrinos: $< 10 \% \text{ GW}$
- Future: Receive / send alerts in real time



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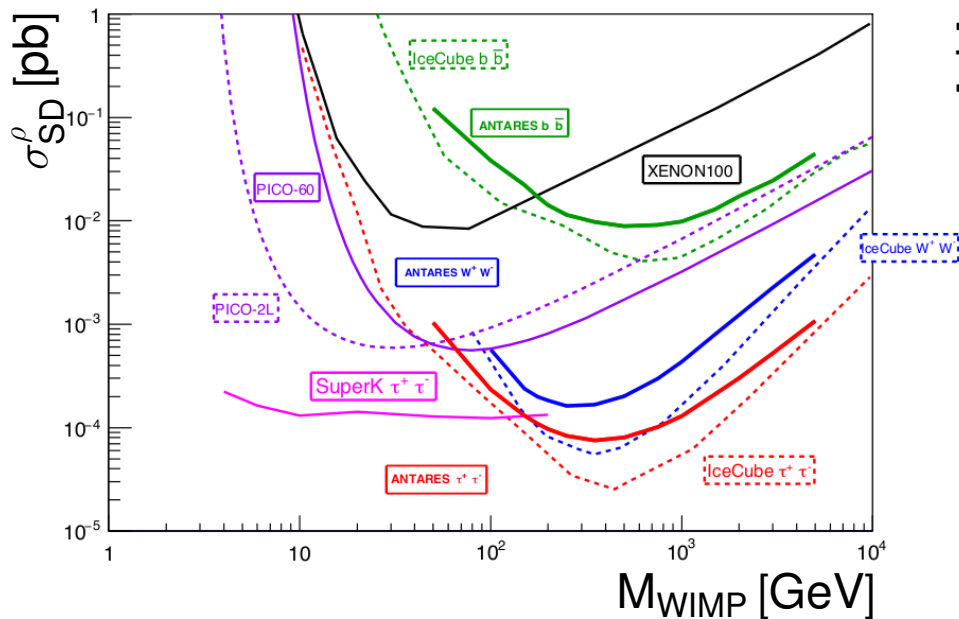
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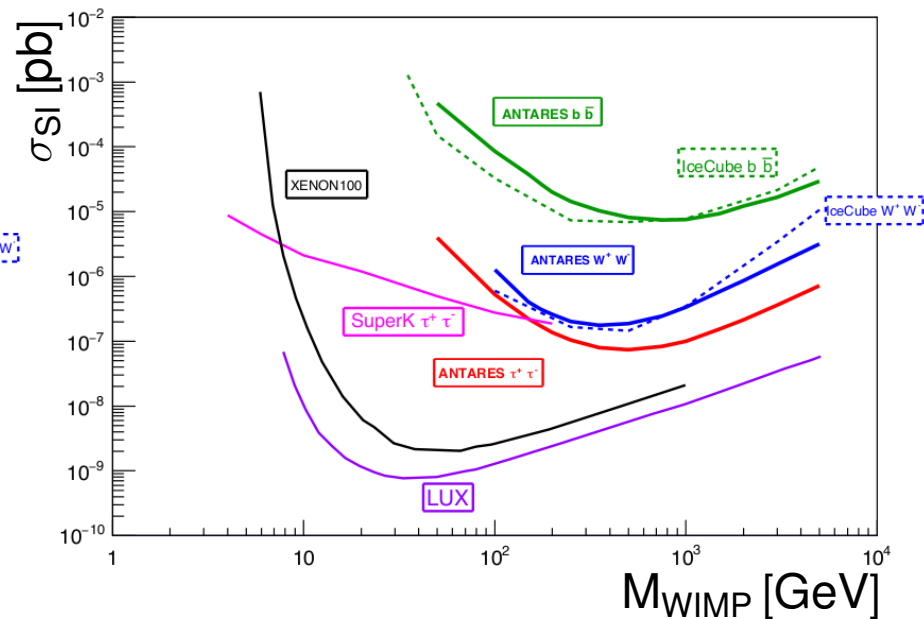


Dark Matter search from the Sun

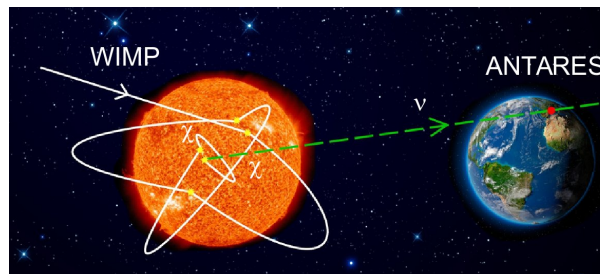
- 1321 days of livetime of muon tracks during 2007–2012



Spin dependent

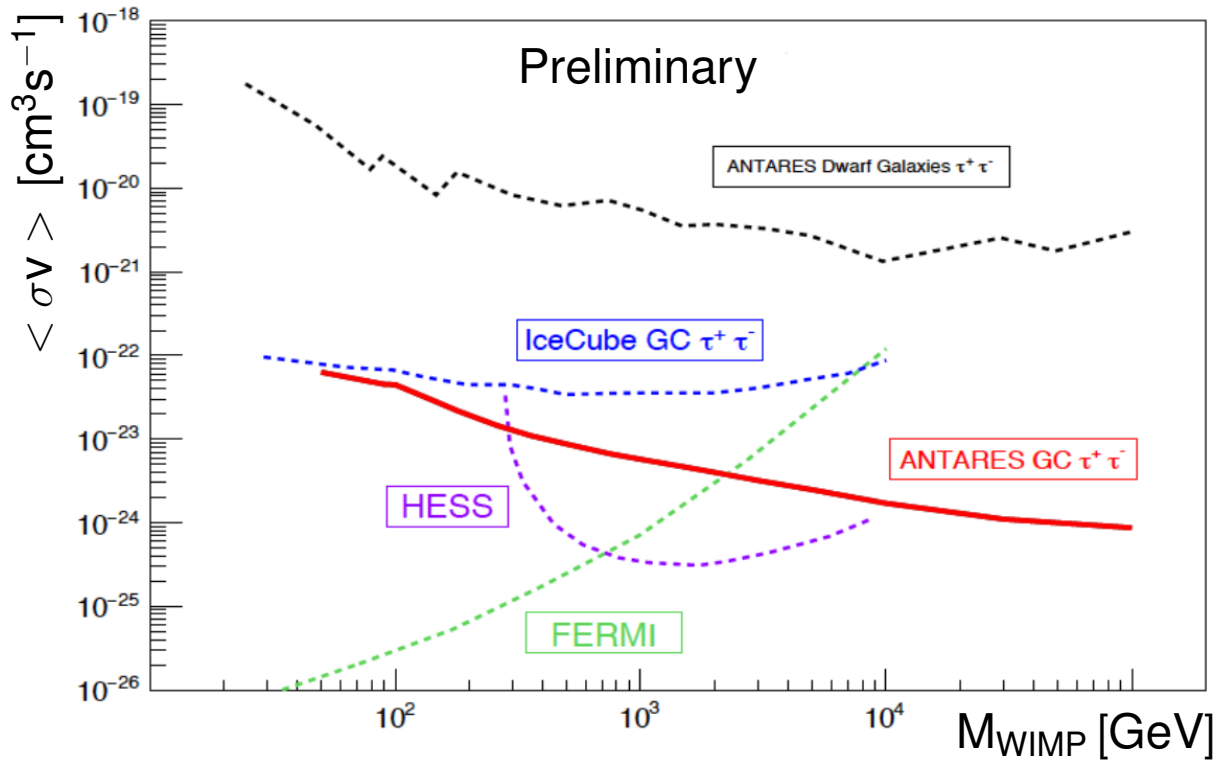


Spin independent



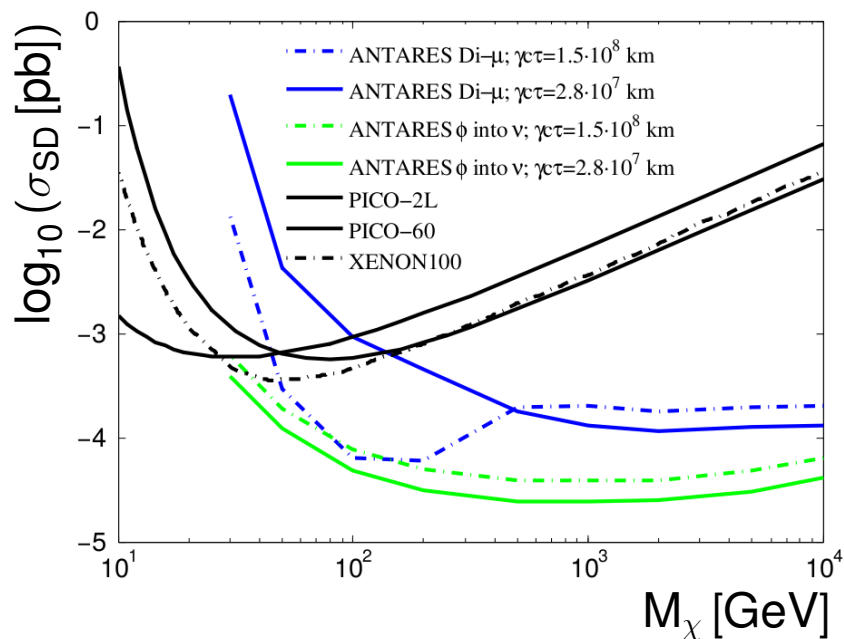
Dark Matter search from the Galactic Center

- Muon tracks in data from 2007 – 2013
- Competitive results, constraining SUSY dark matter

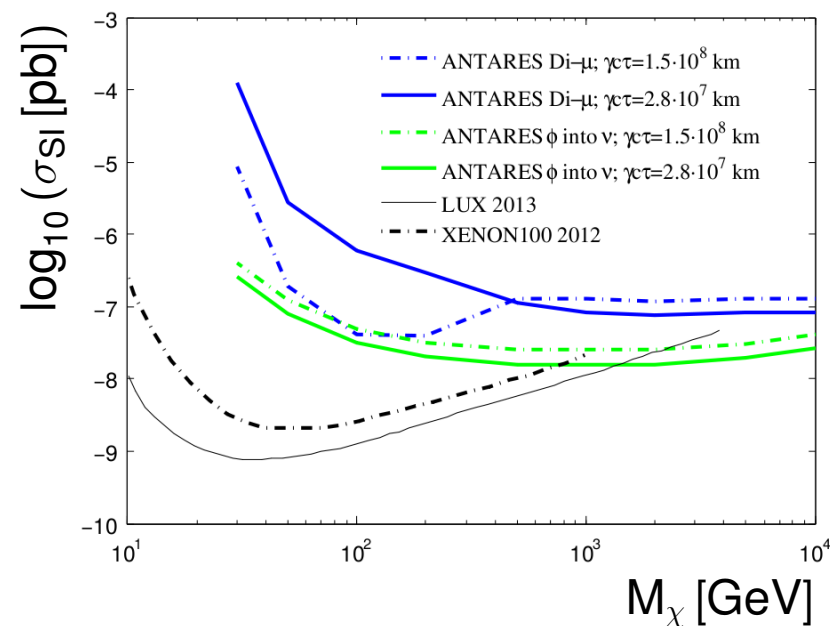


Secluded Dark Matter search from the Sun

- Dark matter secluded by a mediator: detection by mediator which eventually decays in neutrinos
- Sun as the source candidate
- 1321 days of livetime of muon tracks during 2007–2012
- Limits inferred in the absence of excess of signal



Spin dependent



Spin independent



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- Only a fraction of the physics program of ANTARES could be covered here
- Complementary results to IceCube and experiments from different fields
- Constraints on the origin of the IceCube signal
- Large multimessenger efforts
- Excellent angular resolution, view of Southern sky, competitive sensitivities
- Improvements still to come: include showers in all analyses
- Demonstration of the great potential of deep-sea Neutrino Telescopes
- ANTARES will keep producing results until the next generation Mediterranean neutrino telescope, KM3NeT, takes over

